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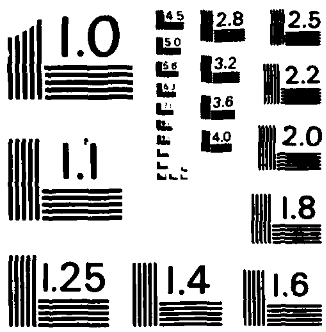

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Technical Document 293

BOILER TUBE INSPECTION DEVICE

Fiber optics provides small, flexible system for full-length inspections

DB Forman
Design Engineering Division
Code 924

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Prepared for
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NAVAL OCEAN SYSTEMS CENTER
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This Technical Document describes a shipboard boiler tube inspection system using coherent fiber optics technology to permit full length inspection of boiler tubes for maintenance and repair. A small, flexible fiber optic bundle with a wide angle lens is used to locate foreign objects, and flaws in the tube walls. A video recording unit is used to provide a visual record of each tube inspected. The fiberscope system has been used successfully aboard ship to identify problem areas such as boiler tube blockage due to foreign objects. Heretofore, boiler tubes often had to be cut open, or expensive X-ray or radiograph equipment used to locate and identify a problem.

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CONTENTS

EXECUTIVE SUMMARY

The ability to maintain machinery aboard ship is directly related to how well the maintenance personnel can find and solve problems. In dealing with machinery the most important part of the inspection is the ability to see the area where the problem has occurred. Inspection equipment available to maintenance personnel for visual inspection is very limited. In many cases the machinery must be dismantled to permit inspection. The inspection of boilers goes even further. Sample tubes must be cut out and destructively tested because of the inability to visually inspect the inside of the tube over the entire length. This project was proposed in an effort to overcome these inadequacies in the inspection process.

NOSC, with the help of fleet maintenance personnel, has developed an inspection system, using fiber optics, that will allow maintenance personnel to visually inspect the inside surfaces of boiler tubes as well as other inaccessible areas. The system consists of a 15-foot coherent fiber optic cable with a wide angle lens, a video camera/monitor, and a video recording system. This system is packaged to be portable and can be operated by maintenance personnel.

This system has been used by COMNAVSURFPAC for a variety of applications in addition to its prime use, which is the inspection of boiler tubes. Fleet maintenance personnel associated with this project report that this type of device is a great benefit to the Navy. Even in limited field testing it has shown a large savings of time and money. (See Appendix B, Shipboard Test Reports.)

Further development for the production engineering of this system has not been funded, though many fleet organizations indicated an urgent need for this equipment.

BACKGROUND

The Navy has found that with proper care, the life of shipboard boiler tubes can be significantly extended. The problem is in knowing the exact condition of the tubes at any time. Without this knowledge, one cannot predict the life or make small changes in the care of the boiler that could significantly extend the serviceable life.

At the present time, there are two ways to establish the condition of a boiler tube. One is to cut out a representative sampler of boiler tubes. The tubes are then split open and visually and mechanically checked. This type of destructive testing is costly and does not yield truly accurate results. Until now, this was the only way to visually inspect the inside surface of a boiler tube over its full length.

The second type of inspection is the British boiler tube inspection device, which is non-destructive. This device visually checks the inside surface and, through ultrasonic means, checks the wall thickness of the tube. Because of equipment limitations, ultrasonic inspection is only performed at each end of the tube and cannot exceed a depth of 29 inches into the tube, or to the first bend. However, the vast majority of boiler tubes are 15 to 30 feet long.

The Navy also has an on-going problem with blockage within pipe lines and boiler tubes. This can be caused by objects such as nuts, bolts, tools, etc., being lost in the line. When this happens, the problem is how to locate the object with the least amount of damage to the tubes or lines. The present way the Navy locates these problems is with mirrors, lights, mechanical fingers, hooks, X-ray and radiographs. Unfortunately, in many

cases, the cutting torch is used or the whole system is removed. The cost of removal is staggering. In many cases the object adrift is no larger than a small nut or bolt.

All of the above techniques were studied and the decision reached that advanced technology, namely the use of fiber optics, would provide a better, faster, and more economical means of inspecting shipboard boiler tubes.

DESIGN GOAL

The goal of this program was to develop a fiberscope for the inspection of shipboard boiler tubes. The widespread use of coherent fiber optics in industry is just now starting to emerge. The fiberscope system developed in this program, as shown below in figure 1, is the first of its kind for the following reasons:

1. A wide angle, fixed focus camera lens is used.
2. All parts of the system are replaceable (not potted throw away).
3. The system is ruggedized to withstand the rigors of shipboard environment.
4. The fiber optic bundle is coherent and round in format to take advantage of the wide angle lens which gives the maximum resolution with minimum size bundle.
5. The full length of a boiler tube can be inspected.

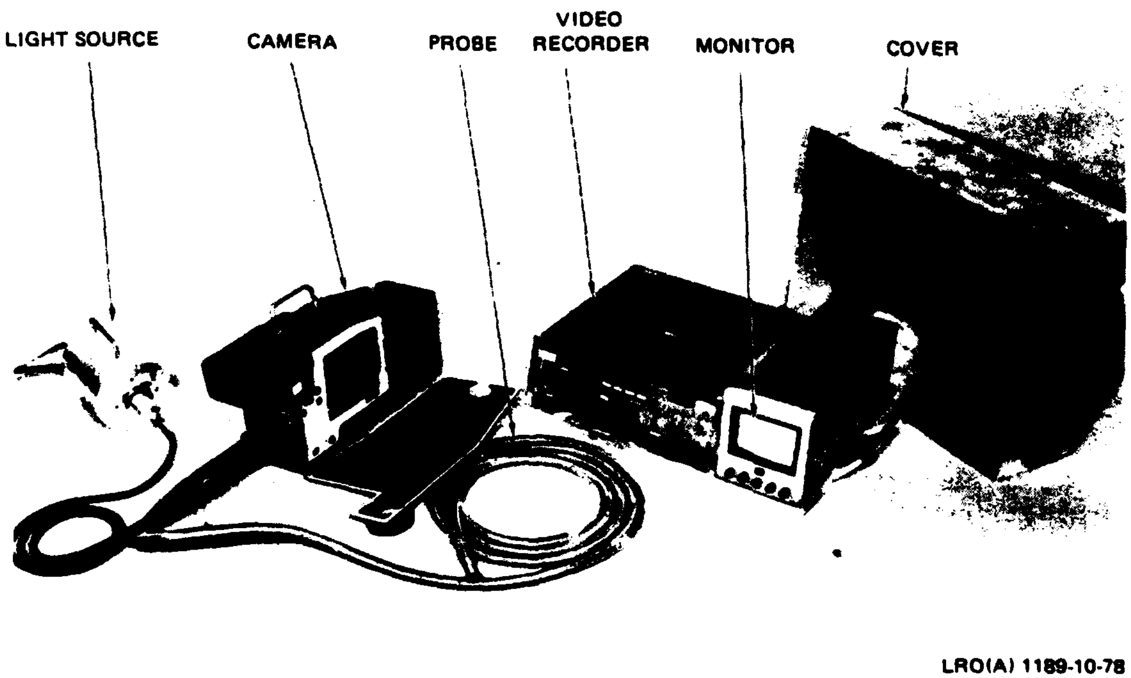

Figure 1. NOSC-developed fiberscope system for shipboard boiler tube inspections.

DESIGN APPROACH

DESIGN FEATURES ESTABLISHED

At the start of this effort, NOSC, with the help of the Naval Development and Training Center/Fleet Maintenance Assistance Group Pacific (DATC/FMAGP), Code 5000, defined the system and operational requirements for an inspection device designed by NOSC. The most important requirements established were that the device be simple to operate and that boiler inspectors could easily use the device aboard ship. With these points in mind, the following are features that an inspection device should incorporate:

A. Visual inspection over the full length of the boiler tube, and an ultrasonic check of the tube wall thickness when needed.

B. Fiber bundle and lens portion of the device small and flexible enough to pass through all bends and neck-down areas of the boiler tubes.

C. When viewing an object or flaw in a tube, the inspector should be able to estimate the approximate size of the discrepancy.

D. Provide an image that would permit an inspector to make correct judgments as to the nature and extent of the problem.

E. Automatically record the condition of the boiler tubes.

F. Operation of the device should be simple and operated with minimum instructions.

G. The ability to withstand shipboard environment.

To the extent possible, the design of the boiler tube inspection device incorporated these seven features.

Full Length Inspection

The first design goal was to inspect the full length of the boiler tube. The longest, commercially available fiberscope that is built by normal production means is 15 feet long. The longest boiler tubes are approximately 28 feet long. Therefore, because boiler tubes are open and accessible at both ends, a distance of up to 30 feet can be optically inspected.

The ultrasonic head was developed to fit the smaller boiler tubes, but the area inside the tubes is so small that the fiberscope and ultrasonic head have a tendency to hang up. Boiler inspectors associated with ultrasonic inspections feel that the only areas that the boiler tubes are thin is at each end. Therefore, ultrasonic inspections should be made at these points because of the heavy pitting and fireside thinning which occurs in these areas. The ultrasonic check of the full length of tube would give little new data and was, therefore, not considered a prime design goal.

Small, Flexible Unit

The second goal was to have a small and flexible unit. The first fiberscope purchased was flexible enough but too large in diameter for the smallest tubes in a boiler. A redesign was made and the overall size reduced. Also, in field testing the large fiberscope, it was evident that the high resolution of the large fiberscope was not as necessary as the need for a fiberscope with a smaller diameter. The new, smaller fiberscope is approximately three quarters the diameter of the original fiberscope, but the overall performance of this new fiberscope is as good or better than the original fiberscope even though the resolution is somewhat less.

Problem Area Size

The third design goal was the determination of the size of a discrepancy. This was made possible by the wide-angle lens which gives a full, 360° view of the tube walls in the round format. The inspector knows the size of the tube under inspection and thus the size of the discrepancy is easily estimated by comparing the size of the discrepancy and the tube's diameter.

Judgment Factor

The fourth goal was attained by using a lens with a large depth of field and a high resolution fiber optic bundle. In the testing phase, the ability to make correct judgments was evidenced from the use of the fiberscope by inspectors in troubleshooting problems in fleet ships. The fiberscope has been used a number of times to find objects in boiler lines. When the fiberscope was inserted in the line, the problem was either isolated or, many times, and of more importance, the absence of a problem in that tube was established. An arc lamp is the light source for the fiberscope.

The fifth goal was attained by using a video camera and tape system. The ability to video tape the results has proven to be a great asset in proving the existence of a problem. The video tape will give a visual record of the condition of the boiler which is more reliable than opinions based on limited data. Previously, the visual inspection was made at each end over tube lengths of only a few inches. The inspector was expected to make a judgment as to the condition of the boiler on very limited information. The fiberscope and video tape will now give a record of the full length of the boiler tube observed providing a sound basis for the inspectors' judgment.

Operation Made Simple

The sixth design goal was attained by selecting components that are uncomplicated; therefore, the operation of the boiler tube inspection device is made simple. The lens on the fiberscope is fixed focused and the camera is automatic. The only adjustment made is on the color monitor, the same as a normal home TV set. The Set-Up Guide (Appendix A) is a step-by-step set-up procedure. In the field tests, the operation of the system has never been a problem.

Shipboard Environment

The last design goal is for a system that can withstand shipboard environment. The fiberscope is ruggedly designed and has not failed during any development tests. The outside cover and the lens mounting are stainless steel. The video components are encased in aluminum housings and connectors are shielded. In the field testing, there have been times that the system has had some very rough usage without degradation of performance.

RESULTS

The boiler tube inspection device has proven to be a valuable tool for inspection of boiler tubes and other inaccessible areas. The majority of the requests for help using this fiberscope have been for objects lost in boiler tubes. (See Appendix B for five examples of reports following use of the fiberscope system to solve specific problems.)

In some cases, the device proved that the line was clear and blockage of a line was not the problem as was the case aboard USS STERRETT. On USS JOUETT, a hand-hole cover (figure 2) was found in a desuperheater line. The hand-hole cover was about 30 feet, at the opposite end of the line, from the point that operating personnel thought the blockage was occurring. The savings in X-ray alone, on the USS JOUETT, was in excess of $2500. On the USS ALBERT DAVID, another hand-hole cover was located in alpha boiler using the fiberscope. Operating personnel knew the cover had been lost down a desuperheater line but did not know its exact location. The cover was located in a few minutes. The other boiler on USS ALBERT DAVID was also checked. A high pressure plug and two bolts with nuts were located. The operating personnel were not aware of these items being lost in the boiler.

This system has also shown phosphate deposits, pitting, and other boiler operation related problems. With the new smaller fiberscope now under fiber testing at COMNAVSURFPAC, the uses of this inspection method have become even greater. For instance, at US Naval Station, San Diego, CA, it has been used to check for foreign objects, possible sabotage, in the main reduction gears (figure 3) on the USS LANG (FF1060). The fiberscope was used to look into areas of the reduction gears that are inaccessible by normal inspection methods. With the help of the fiberscope every area was checked with nothing found. Therefore, the reduction gear housing was closed and the ship put back in operation. On another job (figure 4) the fiberscope was used to inspect the main reduction gears and bearings aboard USS CORAL SEA, CVA 43. Babbitt bearing material had been found in the oil strainer associated with the reduction gears and, for this reason, the Babbitt bearings for the main reduction gear were suspect. After a close visual inspection, the bearings showed only normal wear and the ship was put back in service. The probing of a line or other area takes only a few minutes after it is open; results exceed all previous inspection methods; cost is minimal and the availability of valuable fleet assets is significantly increased by the use of this device. The Navy personnel that have used or observed performance of the fiberoptic boiler tube inspection device report that this system has a wide range of applications and will be valuable aboard ship. (Figures 2, 3, and 4 are photographs taken off the TV monitor screen in a dynamic mode.)

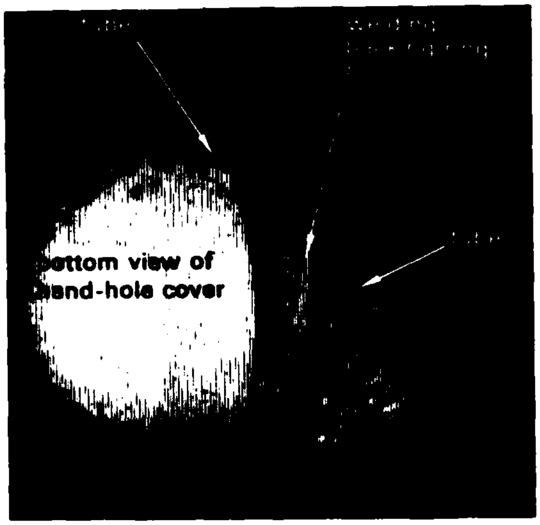

Figure 2. Video tape of hand-hole cover lodged against a backing ring between two welded sections of the desuperheater line aboard USS JOUETT.

Figure 3. Main reduction gears aboard USS LANG (FF 1060)

Figure 4. Reduction gear bearing cap aboard USS CORAL SEA (CVA 43)

RECOMMENDATIONS

1. The Sony DXC-1610 camera should be replaced with a comparable [illegible] camera with a cylindrical or rectangular case, this would be much less expensive [illegible] and provide the same performance for less cost. Experience has demonstrated [illegible] battery power feature of DXC-1610 is no longer required

2. Experience with this device shows that the next phase of the [illegible] should be the development of a retrieval device for lost objects In most cases a simple electromagnet or mechanical finger could solve the problem

3. There should be an engineering development phase to reduce costs, improve packaging, and provide complete documentation of the fiberscope system prior to future procurements.

APPENDIX A

SET-UP GUIDE FOR BOILER TUBE INSPECTION FIBERSCOPE

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SET-UP GUIDE FOR BOILER TUBE INSPECTION FIBERSCOPE

WARNINGS

Do not drop Fiberscope.

Do not use in water or other fluids.

Do not bend the fiberscope in less than a 10-inch diameter.

Use only 110-120-volt, 60-cycle power.

Use only 75-ohm coaxial cable.

Use "C" mount covers when camera/fiberscope are not in use.

Follow the manufacturer's warnings as to the proper care of equipment.

PRELIMINARY INSTRUCTIONS

1. Read the operating instruction for the Sony DXC 1610 color camera.
2. Read the operating instruction for SLO-320 video recorder.
3. Check A-E before going out on job.
4. Check F-Q setting up camera on job.

SET-UP INSTRUCTIONS

1. Check charge on battery adaptor (BP-60), place in Off position when not in use.
2. Place camera in case, being sure video output is connected to the bulkhead connector in the case.
3. The camera cable from the back bottom of the camera is not used in this system.
4. For attachment of camera to case, use bolt in bottom of case.
5. Close cover and check battery switch for Off position.
6. Slide support ring over back portion of fiberscope. Slip approximately 3 inches down on black tube.
7. Remove "C" mount covers on fiberscope/camera. Connect fiberscope to camera "C" mount.
8. Slip support ring up to camera case and attach with thumb nuts.
9. Connect light guide between fiberscope and light source.
10. Connect light source to 60-cycle 155-volt power
11. Connect video output from camera case to video In on monitor; use 75-ohm (RG59) coaxial cable.
12. Plug 115-volt, 60-cycle monitor into video recorder.
13. Plug video recorder into 115-volt, 60-cycle power.
14. Connect video Out from monitor to video In on recorder if the video tape is needed for the test.
15. Turn on camera, monitor, and recorder.
16. To fine-tune picture:
    - (a) Turn contrast to give as light a picture as possible.
    - (b) Adjust bright, color, and hue to give the best picture.
    - (c) Adjust light guide in or out of light source to give the best picture.
17. Follow the operational manual for the camera and recorder.

APPENDIX B

SHIPBOARD TEST AND EVALUATION REPORTS

TEST EVALUATION OF THE FIBERSCOPE

1. **WHAT IS THE PROBLEM?**

   Babbitt bearing material found in oil strainer for main reduction gears.

2. **WHERE IS THE PROBLEM?**

   The Babbitt could possibly be coming from reduction gears main bearings.

3. **HOW MUCH TIME HAS BEEN SPENT ON THE PROBLEM BEFORE THE PROBE IS USED?**

   ?

4. **WHAT WAS THE RESULT?**

   The weep hole at the base of the bearing cap was checked and found that no Babbitt had melted and run out. The bearing looked good.

5. **WHAT IS THE APPROXIMATE COST SAVINGS IN THE USE OF THE FIBERSCOPE VS. THE NORMAL METHODS?**

   The reduction gears would have had to have been pulled and the cost for a CVA class is unknown.

Exhibit 1. USS CORAL SEA test.

TEST EVALUATION OF THE FIBERSCOPE

1. **WHAT IS THE PROBLEM?**

   Possible sabotage of main reduction gears. Locks on covers had been cut.

2. **WHERE IS THE PROBLEM?**

   Main reduction gears.

3. **HOW MUCH TIME HAS BEEN SPENT ON THE PROBLEM BEFORE THE PROBE IS USED?**

   20-man hours.

4. **WHAT WAS THE RESULT?**

   Nothing was found. The scope was used to check in areas that could not be seen by normal means.

5. **WHAT IS THE APPROXIMATE COST SAVINGS IN THE USE OF THE FIBERSCOPE VS. THE NORMAL METHODS?**

   If the reduction gear had been pulled the cost is $200,000.00 plus. This is probably a low estimate.

Exhibit 2. USS LANG test.

TEST EVALUATION OF THE FIBERSCOPE

1. **WHAT IS THE PROBLEM?**

   Lost hand-hole cover in desuperheater line.

2. **WHERE IS THE PROBLEM?**

   Alpha boiler (pressure fired boiler)

3. **HOW MUCH TIME HAS BEEN SPENT ON THE PROBLEM BEFORE THE PROBE IS USED?**

   The ship would not say

4. **WHAT WAS THE RESULT?**

   Found the hand-hole cover in Alpha boiler and also found two bolts and a high pressure plug in Beta boiler.

5. **WHAT IS THE APPROXIMATE COST SAVINGS IN THE USE OF THE FIBERSCOPE VS. THE NORMAL METHODS?**

   The 6" line would be cut out, the hand-hole cover removed, and tube replaced and requalified. Cost (?)

Exhibit 3. USS ALBERT DAVID test.

TEST EVALUATION OF THE FIBERSCOPE

1. **WHAT IS THE PROBLEM?**

   Blockage in desuperheater line.

2. **WHERE IS THE PROBLEM?**

   Forward boiler–this line is same line that was blocked on USS JOUETT.

3. **HOW MUCH TIME HAS BEEN SPENT ON THE PROBLEM BEFORE THE PROBE IS USED?**

   2 days – 3 men

4. **WHAT WAS THE RESULT?**

   The line was found to be open and the problem was not due to blockage but possible valve malfunction.

5. **WHAT IS THE APPROXIMATE COST SAVINGS IN THE USE OF THE FIBERSCOPE VS. THE NORMAL METHODS?**

   No estimate.

Exhibit 4. USS STERRETT test.

TEST EVALUATION OF THE FIBERSCOPE

1. **WHAT IS THE PROBLEM?**

   Blockage of desuperheater line.

2. **WHERE IS THE PROBLEM?**

   Forward boiler desuperheater line, the line is approximately 30 feet and runs from aft to forward area of boiler.

3. **HOW MUCH TIME HAS BEEN SPENT ON THE PROBLEM BEFORE THE PROBE IS USED?**

   4 days – 3 men.

4. **WHAT WAS THE RESULT?**

   Time on job approximately 45 minutes. Hand-hole cover found in area of a weld. 3.5 feet from opening.

5. **WHAT IS THE APPROXIMATE COST SAVINGS IN THE USE OF THE FIBERSCOPE VS. THE NORMAL METHODS?**

   $2,500.00 X-ray

Exhibit 5. USS JOUETT test.

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